HetNet | Interference Control Technology | CA

Technology Reports

Further Development of LTE/LTE-Advanced – LTE Release 10/11 Standardization Trends –

Heterogeneous Network Capacity Expansion Technology for Further Development of LTE/LTE-Advanced

Recent years have seen a dramatic increase in mobile traffic due to the spread of smartphones and other mobile devices. An effective means of expanding capacity under these conditions –especially in urban areas with extremely high traffic– is to set up a large number of small cells having relatively low transmission power and to use them for offloading radio traffic from macrocells. This article describes capacity expansion technologies introduced by 3GPP in LTE Release 11 specifications (LTE-Advanced) for heterogeneous networks that overlay small cells on top of macrocell coverage.

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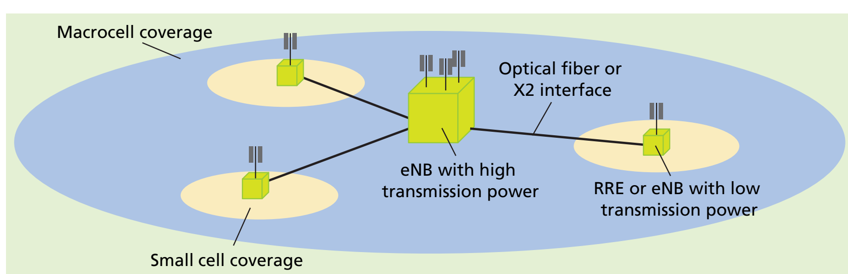
1. Introduction

At the 3rd Generation Partnership Project (3GPP), the Heterogeneous Network (HetNet) has come to be standardized in response to dramatic increases in mobile traffic as the use of smartphones and other mobile devices continues to grow. A HetNet deployment expands capacity in the radio access network by offloading macrocell[*1] radio traffic to small cells having relatively low transmission power. As shown in **Figure 1**, HetNet in 3GPP is defined as a network configuration that overlays small cells having relatively low transmission power (picocell[*2] and femtocell[*3] units) on top of macrocell coverage with a base station (eNB) having higher transmission power. In short, HetNet makes it possible to flexibly expand radio capacity by



eNB: eNodeB
X2 interface: Wired transmission path for exchanging control information between eNBs.

Figure 1 Heterogeneous Network (HetNet)

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*1 **Macrocell**: Cellular communication area with a cell radius of several hundred meters to several tens of kilometers mainly covering outdoors. Antennas are usually installed on towers or on roofs of buildings.

*2 **Picocell**: A cell having a radius of from several tens of meters to about a hundred meters configured for indoor or outdoor use.

deploying many small cells in outdoor/indoor hotspot[*4] areas that require a large amount of capacity. At the same time, inter-cell interference between a macrocell and small cells and between small cells themselves must be considered, and this issue has led to the introduction of technologies such as Coordinated Multi-Point (CoMP)[*5] transmission/reception and Inter-Cell Interference Coordination (ICIC)[*6] [1].

In this article, we describe these HetNet capacity expansion technologies with a focus on functions that were introduced and extended mainly in LTE Release 11 specifications (hereinafter referred to as "LTE Rel. 11").

2. CoMP Transmission/ Reception Technology

The CoMP transmission/reception technology coordinates the sending and receiving signals among multiple cells to and from single User Equipment (UE). The coordination of transmission/reception signals between multiple cells can improve cell-edge user throughput[*7] due to interference reduction between adjacent cells.

2.1 Study Scenario at 3GPP

As described earlier, the HetNet configuration consists of different types of transceiver nodes having different levels of transmission power. In addition to the high-power macro eNB[*8], there is also the pico eNB[*9] having low transmission power as well as the femto eNB[*10] and relay eNB[*11] having even lower transmission power and granting access rights to only some UEs. In a LTE Rel. 11 CoMP study, optical fiber was assumed between a macro eNB and Remote Radio Equipment (RRE)[*12] or between RREs. Studies were also performed on CoMP technology targeting not only the case in which a macro eNB and RRE each have a different cell ID[*13] but also the scenario in which two transmission points share a common cell ID thereby reducing the frequency of handover[*14] actions [2]. Specifications were formulated envisioning the possibility of both scenarios.

2.2 Downlink CoMP Transmission Technology

1) CoMP Transmission Methods

Although there are several transmission methods in downlink CoMP transmission technology, this article describes the Dynamic Point Selection (DPS) method, which is relatively simple compared to the other methods and which turned out to be the main target of LTE Rel. 11. As shown in **Figure 2**, the DPS transmission method instantaneously selects a transmission point to transmit the Physical Downlink Shared CHannel (PDSCH) based on channel quality information at that point. In addition, DPS can be combined with Dynamic Point Blanking (DPB) to mute the interference from neighboring cells thereby improving the received Signal to Interference plus Noise power Ratio (SINR)[*15] of cell edge UE.

2) Reference Signal Enhancement

The LTE Rel. 10 specification introduced two types of downlink reference signals (for measuring channel quality and data demodulation), but LTE Rel. 11 introduced reference-signal scrambling[*16] based on a virtual ID assigned to individual UE in contrast to the conventional scheme of applying cell-specific scrambling to those reference signals. This makes it possible to allocate radio resources[*17] in a flexible manner independent of a fixed cell ID assigned to each transmission point. For example, interference can be randomized by having multiple, adjacent trans-

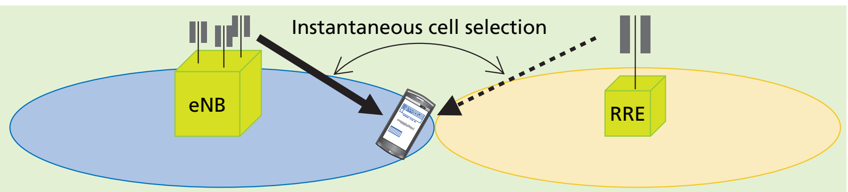


Figure 2 Downlink CoMP transmission (DPS)

*3 **Femtocell**: A cell covering an extremely small area with a radius of up to several tens of meters for homes or small shops.

*4 **Hotspot**: A place where traffic is generated in concentrated form such as a plaza or square in front of a train station.

*5 **CoMP**: A technology for sending and receiving signals to and from multiple sectors or cells with respect to a certain UE. Dynamically coordinating the transmission/reception of multiple cells reduces inter-cell interference and/or increases the desired signal power.

*6 **ICIC**: A technology that reduces the effects of inter-cell interference by semi-statically allocating different time/frequency radio resources between cells.

*7 **User throughput**: The amount of data that one user can transmit without error per unit time.

*8 **Macro eNB**: A eNB configuring a macrocell.

*9 **Pico eNB**: A small eNB configuring a picocell. Transmission power is low compared to a macrocell eNB.

*10 **Femto eNB**: An ultra-small eNB configuring a femtocell. Transmission power is even lower than that of a pico eNB.

*11 **Relay eNB**: eNB that relays radio transmissions from another eNB to a terminal.

mission points transmit signals using different types of scrambling, and conversely, the reference signals can be subjected to orthogonalization[*18] using identical scrambling from multiple transmission points.

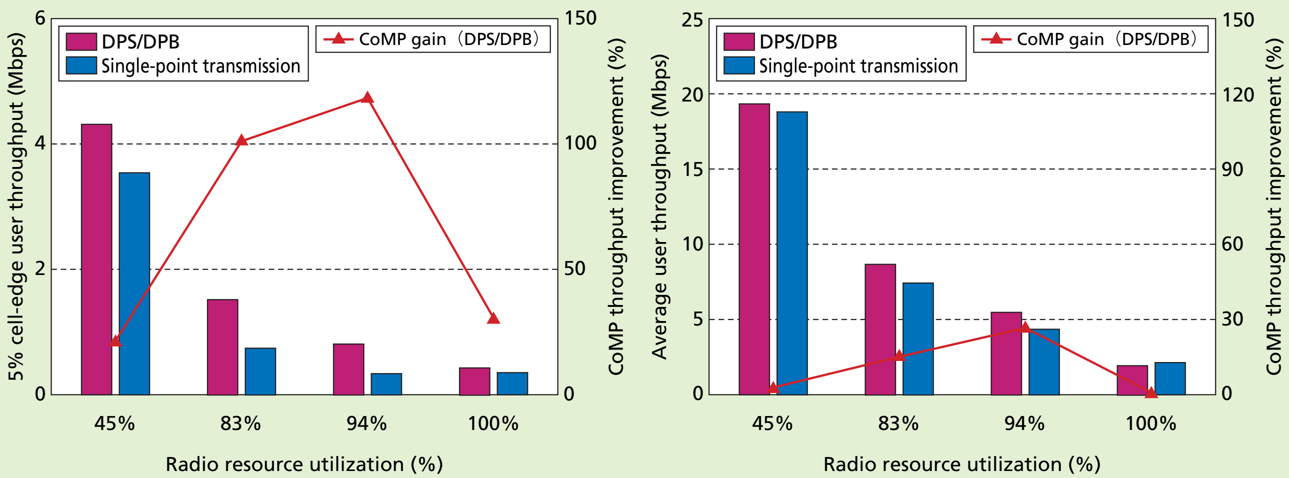
Randomizing the reference signals according to virtual IDs assigned to individual UE was also introduced in the uplink reference signal for data demodulation in the Physical Uplink Shared CHannel (PUSCH)[*19] and the Physical Uplink Control CHannel (PUCCH)[*20].

3) Channel Quality Feedback Enhancement

In CoMP transmission technology, radio resources can be allocated to a single UE from multiple transmission points, which means that the UE can feed back multiple types of channel-quality information taking multiple transmission points into account. The transmission side uses these multiple types of channel-quality information fed back from the UE within coordinated cells to determine the scrambling, CoMP transmission methods as well as the PDSCH allocation to that UE.

2.3 Performance Evaluation

We show throughput improvement of downlink CoMP transmission technology via system level simulation. In this evaluation, we assumed a 19-cell model with each cell having a hexagonal-shaped, 3-sector configuration. The number of coordinated cells was 9 sectors. The maximum number of simultaneously transmitting cells and the maximum number of cells for channel quality information feedback in CoMP was 3. Furthermore, the File Transfer Protocol (FTP)[*21] traffic model in Ref. [3] was assumed with a 2 MB download file size for each UE. Detailed evaluation parameters are based on the common assumption in 3GPP [4]. **Figure 3** (a) and (b) show 5% user throughout performance (5% with respect to the user-throughput cumulative probability density distribution) and average user throughput performance, respectively. The horizontal axis shows different amounts of generated traffic per unit time (corresponding to radio resource utilization). The vertical axis shows the throughput improvement of CoMP compared to conventional single-point transmission. We here applied the CoMP transmission method described in section 2.2 (DPS and DPB combined method). The results show that user



(a) cell edge (5% value of CDF) user throughput performance

(b) Average user throughput performance

Figure 3 3 Downlink CoMP throughput performance

*12 **RRE**: eNB antenna equipment installed at some distance from an eNB using optical fiber or other means.

*13 **Cell ID**: Identifying information assigned to each cell.

*14 **Handover**: The process of switching the eNB connected to the UE.

*15 **SINR**: The ratio of desired-signal power to the sum of all other interference-signal power and noise power.

*16 **Scrambling**: Randomizing by a process that multiplies code sequences.

*17 **Radio resource**: Unit of time or frequency range allocated to each user for communication purposes.

*18 **Orthogonalization**: When multiple signal series are multiplexed and transmitted in the same radio system band, the process of adjusting them so they do not interfere with each other (making them orthogonal).

*19 **PUSCH**: Physical channel used for sending and receiving data packets in the uplink.

*20 **PUCCH**: Physical channel used for sending and receiving control signals in the uplink.

*21 **FTP**: A protocol that is generally used for transferring files over a TCP/IP network such as the Internet.

throughput performance can be improved by applying CoMP for the same radio resource utilization rate. Compared to single point transmission, about 100% cell-edge user throughput improvement was obtained by CoMP when 83% radio resource utilization is assumed.

3. Enhancement of HetNet Interference Coordination Technology

3.1 LTE Rel. 10 eICIC Technology

As described above, a HetNet deployment consists of pico eNBs superimposed on the area covered by a macro eNB. Here, assuming a scheme in which a UE connects to the cell with the highest Reference Signal Received Power (RSRP)[*22] in the downlink, the number of UEs connected to pico eNBs with low transmission power will be much smaller than the number of UEs connected to macro eNBs with high transmission power. This scheme consequently limits the offload effect and capacity expansion effect obtained by deploying picocells. As shown in **Figure 4**, this issue has been solved by supporting Cell Range Expansion (CRE) [5], which raises the selection rate of picocells by applying an offset value to the RSRP of those cells to expand the equivalent cell radius. In CRE, higher-layer signaling [6] is used to inform each UE of the offset value to be used. With CRE, more UEs can be connected to picocells thereby increasing the offload effect. On the other hand, especially in the downlink, the RSRP from picocells that UEs connect to will become increasingly smaller than that from macrocells as the CRE offset value increases, which means that UEs will be offloaded to a picocell that may be non-optimal from the viewpoint of RSRP. There is therefore a need to apply ICIC to reduce interference from macrocells [7][8]. Since the effects of interference from picocells is typically small in a HetNet deployment, only a macrocell need mute transmissions of some resources or reduce transmission power to protect UEs connected to picocells.

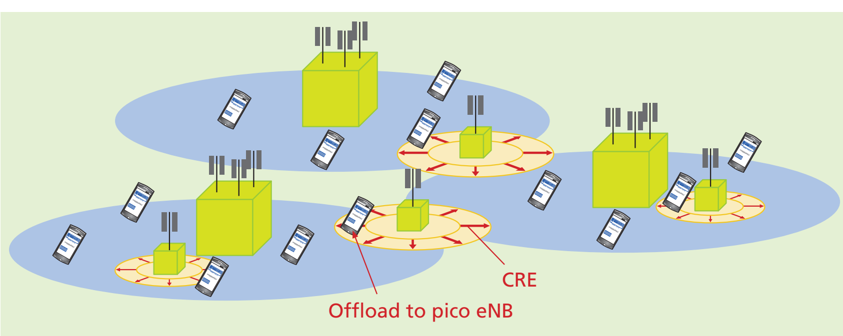


Figure 4 CRE in HetNet

The LTE Rel. 10 specification provides for ICIC in which the macrocell mutes transmission of specific resources in the time domain (subframe). This version of ICIC in LTE Rel. 10 is called enhanced ICIC (eICIC), which, as shown in **Figure 5**, defines an Almost Blank Subframe (ABS) that transmits only a synchronization signal, system information and other control information, and a Cell-specific Reference Signal (CRS)[*23]. In this way, eICIC supports inter-cell interference coordination by defining a subframe that transmits no Layer 1 or Layer 2 (L1/L2) control information or data signals and by coordinating the position and usage rate of these ABSs between cells in the time domain. In the following, radio resources for which interference affecting a UE connected to a picocell is reduced by ABS transmission are called protected resources and all other resources are called non-protected resources. The ratio of protected and non-protected resources must be set appropriately according to the ratio of UEs connected to a macrocell and those connected to picocells. Information on ABS position and usage rate, meanwhile, is passed on to the pico eNB from the macro eNB via the X2 interface as an ABS pattern.

*22 **RSRP**: The received power of a signal measured by a mobile terminal in LTE. Used as an indicator of the receiver sensitivity of mobile terminals.

*23 **CRS**: A reference signal specific to each cell for measuring received quality in the downlink.

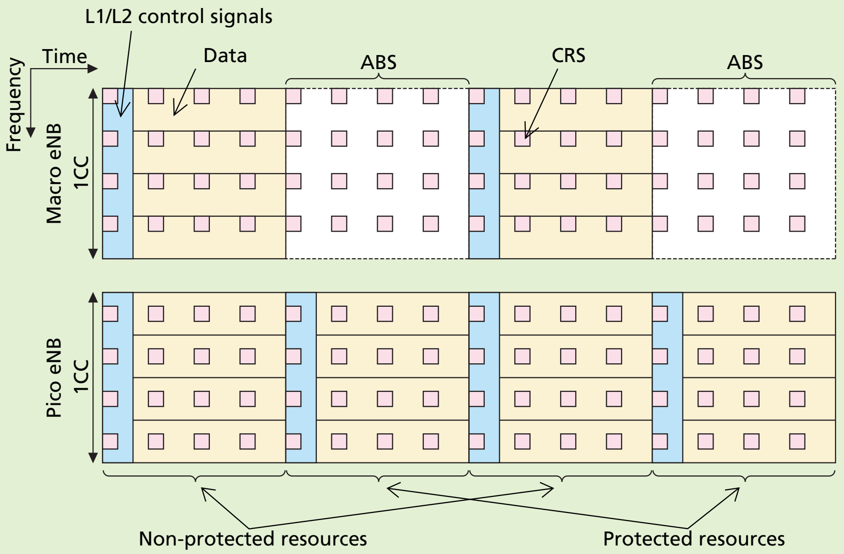


Figure 5 eICIC

Furthermore, when applying eICIC, the received quality at a UE connected to a picocell differs greatly between protected and non-protected resources. Accordingly, to facilitate the efficient execution of various control tasks such as Adaptive Modulation and Coding (AMC)[*24] and scheduling, a UE connected to a picocell must feed back two types of Channel State Information (CSI)[*25] representing the received quality of protected and non-protected resources. In LTE Rel. 10, a network can inform the UE of resources for measuring the CSI of protected and non-protected resources.

3.2 LTE Rel. 11 eICIC Technology

To increase the offload effect by CRE, it was decided that a CRE offset value up to 9 dB would be supported in LTE Rel. 11. Consequently, for a CRE offset value set to this maximum value of 9 dB, a UE connected to a picocell at the boundary between a macrocell and picocell would receive interference from the macrocell 9 dB higher than the power received from the connected picocell. When applying eICIC, CRS is always transmitted even in an ABS to measure received quality at handover and for other purposes, which means that the data signal of the UE offloaded to a picocell by CRE will receive interference from the CRS transmitted by the macrocell. Furthermore, when applying CRE, a UE at the cell boundary between a macrocell and picocell must receive synchronization signals and control information from the picocell in a state in which much interference is being received from the macrocell. Accordingly, to improve transmission characteristics even further when applying eICIC, LTE Rel. 11 specifies (1) an interference canceller on the UE side targeting the CRS from a macrocell and (2) Radio Resource Control (RRC)[*26] signaling for cancelling CRS interference and receiving system information at the cell edge when applying CRE. Each of these measures is summarized below.

(1) CRS interference canceller

Cancels interference from CRS given to a UE offloaded to a picocell with a high CRE offset value and cancels CRS from the two neighboring cells with the highest interference power.

(2) RRC signaling

- Specifies subframe information including number of neighboring cells, cell IDs, number of CRS ports, and subframes containing the CRS as signaling for cancelling CRS interference.
- To enable the reception of System Information Block (SIB)[*27]-1 information at a cell edge when applying CRE, provides for the transmission of SIB-1 using individual signaling for the cell (picocell) receiving interference.

*24 **AMC**: A method for adaptively controlling transmission data rate by selecting an optimal data modulation method and channel coding rate according to received quality such as the received SINR.

*25 **CSI**: Information describing the state of the radio channel traversed by the received signal.

*26 **RRC** Layer 3 protocol for controlling the radio resources.

*27 **SIB**: A specific block of system information broadcast from an eNB to mobile terminals. There are multiple types of SIBs.

4. Enhancement of CA Technology

Carrier Aggregation (CA)[*28] was introduced in LTE Rel. 10 as a function for achieving broadband communications of greater than 20 MHz while maintaining backward compatibility with LTE Rel. 8 [9]. It improves the peak data rate by using multiple instances of a LTE Component Carrier (CC)[*29]. In particular, utilizing CA in a HetNet environment between a macrocell and small cells operating on difference frequencies enables data offloading to small cells while keeping connectivity and mobility performance with the eNB of the macrocell. Offloading to small cells can also be achieved for uplink traffic in addition to downlink traffic, and given that the radius of a small cell is relatively small, high-bit-rate communications can be achieved with relatively low transmission power compared with uplink communications in a macrocell. This is advantageous for the mobile terminal from the viewpoint of battery consumption. One format for applying CA in a HetNet environment is to use it between a macrocell eNB and cells using RRE. However, a macrocell and small cells have different transmission points and cell radii, which means that their signal propagation delays will likewise differ. In fact, the difference between their propagation delays can become quite large given that macrocells and small cells use different frequencies and therefore have different frequency characteristics. In particular, very large differences in the propagation delays of uplink signals can cause orthogonality between users in the cell to collapse thereby creating interference in the uplink.

Against the above background, LTE Rel. 11 introduced Multiple Timing Advances (MTA) as a technology for establishing different UE uplink transmission timings for each cell and reducing the difference in uplink signal delays between UEs in a cell.

4.1 Uplink Transmission Timing Control

Given a LTE system adopting Single Carrier Frequency Division Multiple Access (SC-FDMA)[*30] for uplink communications, the uplink signals received at the eNB from different UEs in that cell will be subjected in bulk to a Fast Fourier Transform (FFT)[*31] and demodulated. However, the signal propagation delays of those UEs differ, and if each UE in the cell transmits uplink signals in time with the downlink signals received from the eNB, the uplink signals from the UEs will be received at the eNB at different times, which means that the eNB will not be able to execute FFT processing with the timing desired. As shown in **Figure 6**, the propagation delay of UE#B transmitting from the cell edge is larger than that of UE#A transmitting from the cell center, which means that the offset from desired reception timing is larger for the uplink signal from UE#B (Fig 6 (1)). For this reason, the eNB adjusts the transmission timing of each UE's uplink signal so that reception timing at the eNB falls in the designated timing window in a process called Timing Alignment (TA) control. Specifically, the eNB measures for each UE the difference between the desired uplink-signal reception timing and the actual uplink-signal reception timing and then instructs the UE to shift its uplink transmission timing by exactly that difference (Fig. 6 (2)). This adjustment process prevents interference from occurring between UE uplink signals in the cell thereby enabling the uplink signals to be demodulated. Here, instructions from the eNB for adjusting uplink transmission timing can be sent to UE by a random access procedure or in a Medium Access Control (MAC)[*32] control element.

4.2 MTA

As described above, the propagation delay differs between CCs aggregated by a UE when applying CA between a macrocell and small cells operating on different frequencies. As a result, uplink transmission timing con-

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*28 **CA**: A technology that achieves high-speed communications through bandwidth expansion while maintaining backward compatibility with existing LTE by performing simultaneous transmission and reception using multiple component carriers.

*29 **CC**: Term denoting each of the carriers used in CA.

*30 **SC-FDMA**: A radio access method that implements multiple access by allocating the signals for different users to different frequency resource blocks while an individual user transmits signals keeping a single carrier waveform.

*31 **FFT**: A fast algorithm for converting discrete time domain data into discrete frequency domain data.

*32 **MAC**: The protocol for mapping between the logic and transport channel.

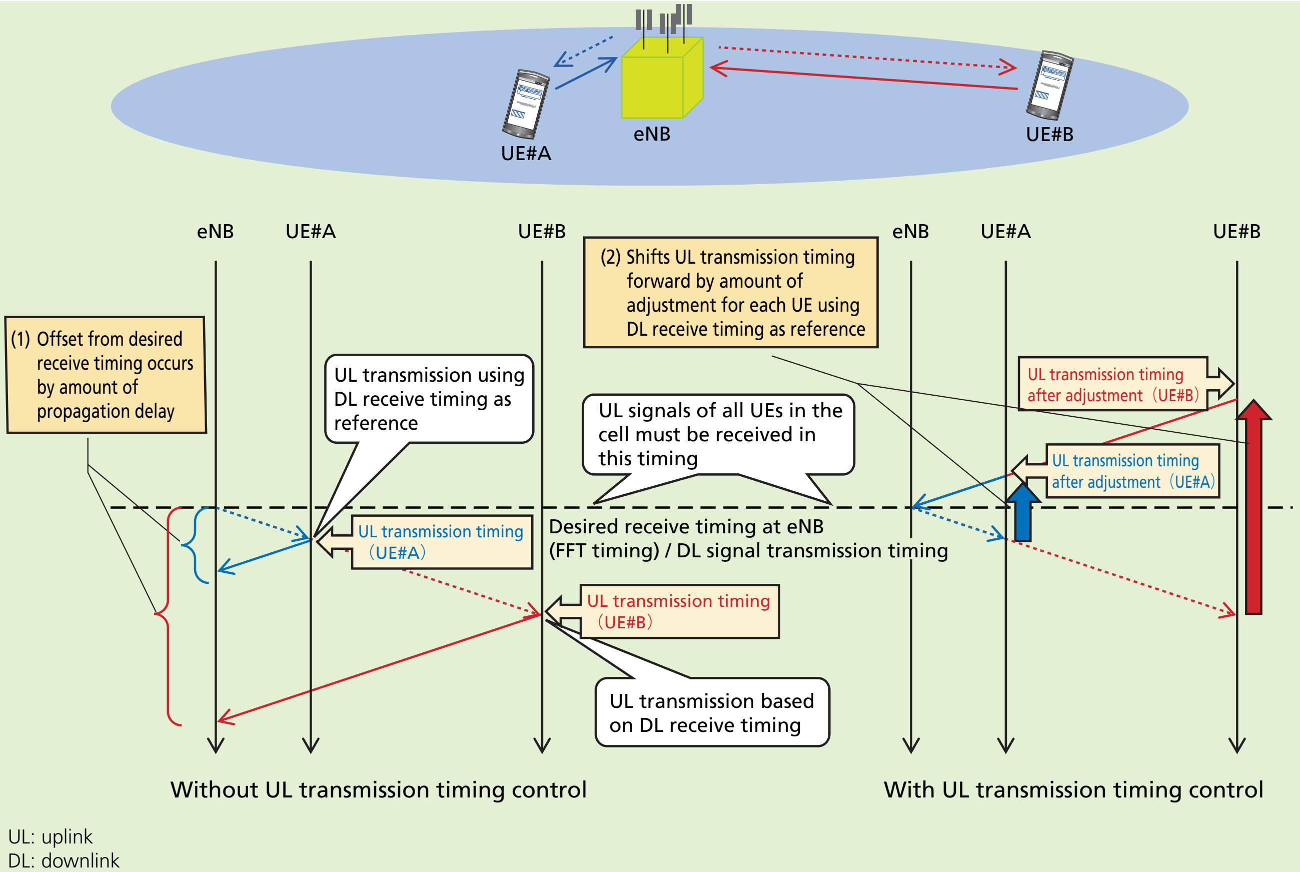

Figure 6 Uplink timing control in LTE

trol in units of UEs up to Rel-10 cannot guarantee orthogonality between UEs in the cell. For example, the left side of **Figure 7** shows the case in which UE#B performing CA with a macrocell and a small cell of RRE is instructed to adjust uplink transmission timing with respect to the macrocell. However, UE#B also applies this timing to uplink transmission in the small cell (Fig. 7 (1)), and as a result, the offset occurs in eNB reception timing between UE#A and UE#B uplink signals in the small cell causing intra-cell interference (Fig. 7 (2)). There is therefore a need to adjust uplink transmission timing for each CC in CA. The measure taken here is to arrange CCs set for a UE into groups having nearly the same propagation delay and to then adjust uplink transmission timing for each of these CC groups, where each group is called a Timing Advance Group (TAG). For example, in the right side of Fig. 7, the eNB measures the difference between desired reception timing and the actual uplink signal reception timing with respect to UE#B for both the macrocell and small cell and instructs the UE to adjust uplink signal transmission timing accordingly for each cell (Fig. (3)). This type of control enables the reception timing of both UE#A and UE#B uplink signals at the eNB in the small cell to fall in the designated timing window and thereby prevent intra-cell interference from occurring. In addition, TAGs are broadly divided into a primary TAG (pTAG) that includes the Primary Cell

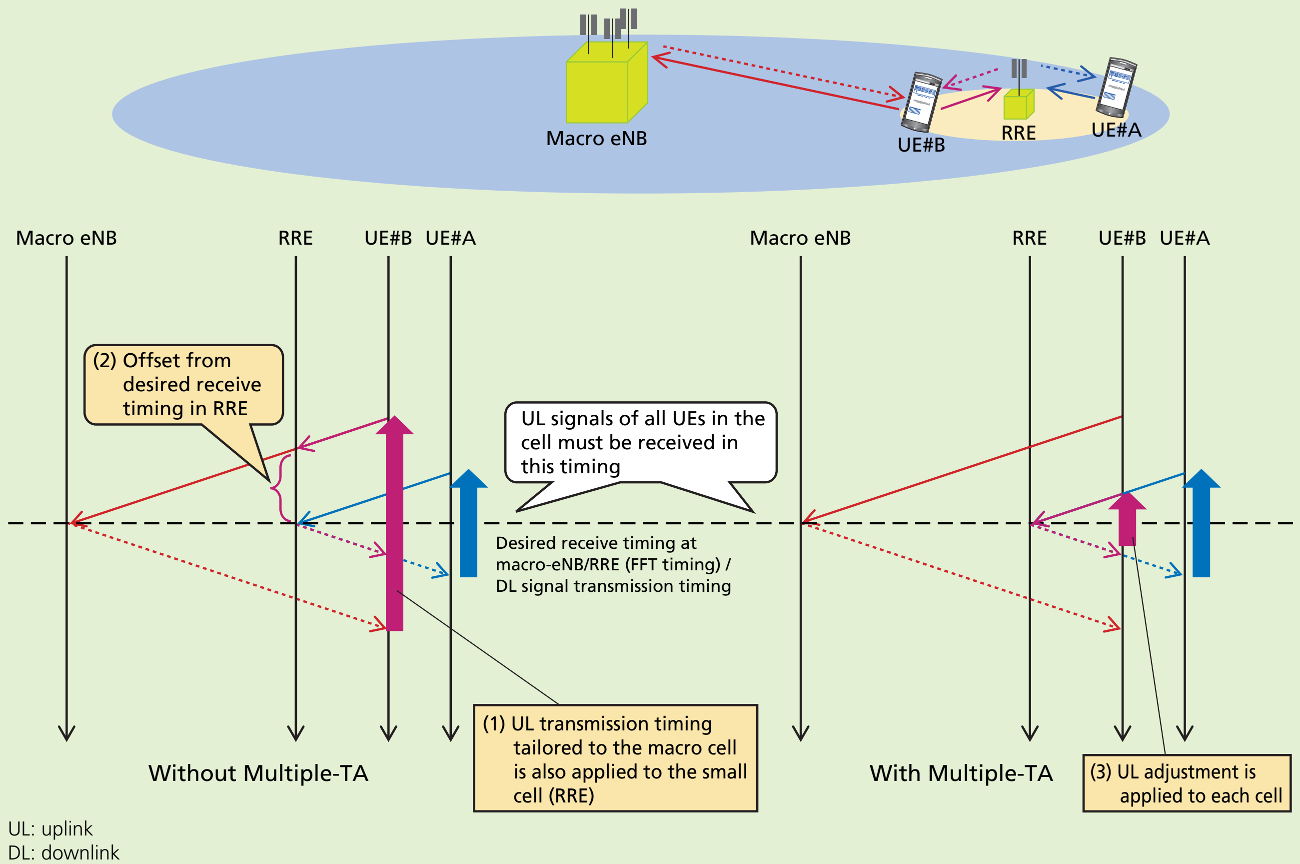

Figure 7 Uplink MTA in CA

(PCell) and a secondary TAG (sTAG) that includes only the Secondary Cell (SCell) in CA. Here, pTAG is controlled as specified up to LTE Rel. 10. On the other hand, sTAG is required to establish the initial uplink transmission timing independently of pTAG, and for this reason, a random access procedure is also supported for the SCell in LTE Rel. 11. Here, though, only a non-contention random access procedure is specified for SCell, which means that this procedure can be initiated only by eNB.

In short, uplink transmission timing adjustment for each CC group having equivalent propagation delay makes it possible to guarantee uplink signal orthogonality between UEs in a cell even when applying uplink CA in a HetNet environment. In addition, uplink CA in LTE Rel. 11 further extends the "combining of uplink signals that can be simultaneously transmitted" beyond uplink CA specified in LTE Rel. 10. Specifically, given that enough transmission power is available for uplink, LTE Rel. 11, in addition to enabling the combining of simultaneous uplink transmissions as enabled by LTE Rel. 10, also supports the simultaneous transmission of Physical Random Access CHannel (PRACH)[*33] –PUCCH/PUSCH/ Sounding Reference Signal (SRS)[*34] from CCs belonging to different TAGs, which makes for more flexible uplink resource allocation and scheduling. However, if uplink transmission power falls short for this

*33 **PRACH**: Physical channel for transmitting the random access preamble.
*34 **SRS**: Uplink reference signal for measuring the channel quality received on the eNB side.

purpose, total transmission power among different TAGs will have to be controlled so as not to exceed the UE's upper limit, and to this end, a transmission power control method has also been specified in LTE Rel. 11 specifications.

5. Conclusion

In this article, we described capacity expansion technologies targeting HetNet deployments in 3GPP with a focus on functions that were introduced and extended mainly in LTE Rel. 11. We expect the introduction of these specifications to facilitate the flexible deployment of small cells in high traffic areas such as urban districts and to secure the radio capacities needed thereby improving the service quality experienced by customers.

References

[1] T. Abe, Y. Kishiyama, Y. Kakura and D. Imamura: "Radio Interface Technologies for Cooperative Transmission in 3GPP LTE-Advanced," IEICE Trans. Commun., Vol. E94-B, No. 12, pp. 3202-3210, Dec. 2011.

[2] 3GPP R1-110649, Ericsson, ST-Ericsson: "Aspects on Distributed RRUs with Shared Cell-ID for Heterogeneous Deployments," Feb. 2011.

[3] 3GPP TR36.814 V9.0.0: "Evolved Universal Terrestrial Radio Access (EUTRA); Further advancements for EUTRA physical layer aspects," Mar. 2010.

[4] 3GPP TR36.819 V11.1.0: "Coordinated multi-point operation for LTE physical layer aspects," Dec. 2011.

[5] A. Khandekar, N. Bhushan, J. Tingfang and V. Vanghi: "LTE-Advanced: Heterogeneous networks," Proc. of European Wireless 2010, pp. 978-982, Apr. 2010.

[6] 3GPP TS36.331 V10.1.0: "E-UTRA; Radio Resource Control (RRC); Protocol specification," May 2011.

[7] M. Sternad, T. Ottosson, A. Ahlen and A. Svensson: "Attaining Both Coverage and High Spectral Efficiency with Adaptive OFDMA Downlinks," Proc. IEEE VTC 2003-Fall, Oct. 2003.

[8] G. Fodor, C. Koutsimanis, A.Racz, N. Reider, A. Simonsson and W. Muller: "Intercell interference coordination in OFDMA networks and in the 3GPP long term evolution system," Academy Publisher Journal of Commun., pp. 445-453, Aug. 2009.

[9] M. Iwamura, K. Etemad, M.H. Fong, R. Nory and R. Love: "Carrier aggregation framework in 3GPP LTE-advanced," IEEE Commun. Mag., Vol. 48, No. 8, pp. 60-67, Aug. 2010.